Driver Performance Measurement To Support Thermal System Development

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Dino Piccione
DCS Corporation
1330 Braddock Place
Alexandria, VA 22314

Don Ferrett
Senior Engineer, Close Combat Support
U.S. Army Project Manager, Night Vision/
Reconnaissance, Surveillance and Target Acquisition
Fort Belvoir, VA 22060

ABSTRACT

The Driver's Vision Enhancer (DVE) program is providing thermal imaging systems to enlarge the driving envelope for the community of military wheeled and tracked vehicles. The DVE provides the driver with thermal images of the forward scene under night and adverse day conditions. During the DVE development program, several questions emerged that required performance-based data to resolve. A multi-phased program to provide the Project Manager, Night Vision/Reconnaissance, Surveillance, and Target Acquisition with driver performance data is described in this paper. The program involves several completed and ongoing efforts including: the relative merits of the DVE and night vision goggles (NVG); drivers' ability to detect the presence of drop-offs when using the DVE and NVG; the analysis of drivers' vision using an eye-tracker; and the effect on performance of various levels of pixel nonuniformity and nonresponsiveness in the display/sensor system. Results will be presented to show the relative capabilities of the various sensors given the environmental conditions of the tests. The data collected has already been used to aid in updating the DVE performance specification for the Thermal Omnibus procurement. The goals of these efforts are to reduce cost without sacrificing driver performance, gain an understanding of how drivers use the DVE in operational settings, and determine where training is needed to enhance performance and reduce risk on the battlefield.

1. INTRODUCTION

The development of night vision devices that can be used by drivers of tactical wheeled and tracked vehicles has its foundation in two main areas. The first is a definition of what the user needs to successfully complete the mission in the operational environment. The second is the technology base that the developer can draw upon to meet those needs. This paper will deal with the driver performance issues that relate to user operational needs. The Project Manager Night Vision/Reconnaissance, Surveillance and Target Acquisition (PM NV/RSTA) developed the Driver's Vision Enhancer (DVE) thermal imaging system for use in combat and tactical wheeled vehicles. This driving aid can be used at night or during the day when vision is obscured. The AN/VAS-5 DVE uses uncooled Forward Looking

Infrared (FLIR) technology as opposed to the image intensification (I^2) technology used in night vision goggles (NVG) and the AN/VVS-2 Driver's Night Vision Viewer. During the development of the DVE,

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several issues were raised concerning how specific aspects of DVE design were related to driver performance. As a result of these issues, a data collection effort was developed to provide the DVE project leader with driver performance data that could act as a foundation for making program decisions. During the initial phases of the data collection project the emphasis was on the application of the DVE to the M2 Bradley Fighting Vehicle and the project took on the informal name of "Driving Miss Bradley." The scope of the program quickly expanded and much of the work done during this effort applies to any vehicle driven with the DVE.

The DVE is composed of two modules; the sensor module and the display module. For the wheeled vehicle variant of the DVE, a pan/tilt system is also included (Figure 1). The DVE is a real-time thermal imaging system operating in the 8-12 micron spectral range. Detectors convert IR radiation from the visual scene into electrical signals. The signals are processed and displayed on a flat panel display. The display is a 5.8 inch X 7.7 inch active matrix liquid crystal display (AMLCD) mounted directly in front of the driver. When used in tactical wheeled vehicle applications, the DVE sensor module is typically mounted on a bracket on the left side of the vehicle, but an alternate location for the sensor on the centerline of the vehicle is being considered. The sensor module pan and tilt system allows the driver to see in front of the vehicle, to the side and behind. The mechanism allows ±170 degrees rotation in azimuth, and +5 degrees to –35 degrees elevation. Early limited production versions of the DVE, such as those procured for U.S. forces in Bosnia, utilized a motorized pan and tilt mechanism. A manually actuated pan and tilt mechanism is being designed to reduce system cost. The sensor has a 40-degree wide by 30-degree high field-of-view (FOV). Objects from 15 feet to infinity are in focus. A right side mirror assembly is available for viewing down that side of the vehicle. The tactical wheeled vehicle DVE display is mounted on a bracket attached to the roof of the driver's compartment. In the combat vehicle version of the DVE (Figure 2), the sensor and display modules are integrated into a single unit. The DVE is mounted in place of the forward periscope (vision block) in the driver's compartment. The sensor FOV is the same as that in the wheeled vehicle version. The sensor on the combat vehicle DVE is manually adjustable to achieve a field of regard of ±50 degrees azimuth and +25 degrees to –15 degrees elevation. Sensor resolution in both versions is 240 vertical by 320 horizontal pixels. Controls for power, polarity, sensor level and gain, and screen brightness are on the display module.

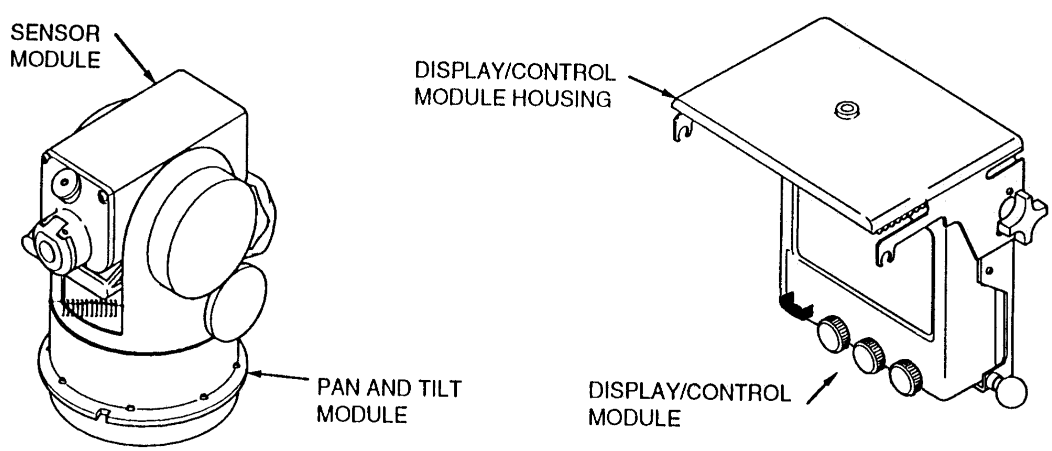

Figure 1. Driver's Vision Enhancer Sensor and Display Modules (wheeled vehicle variant)

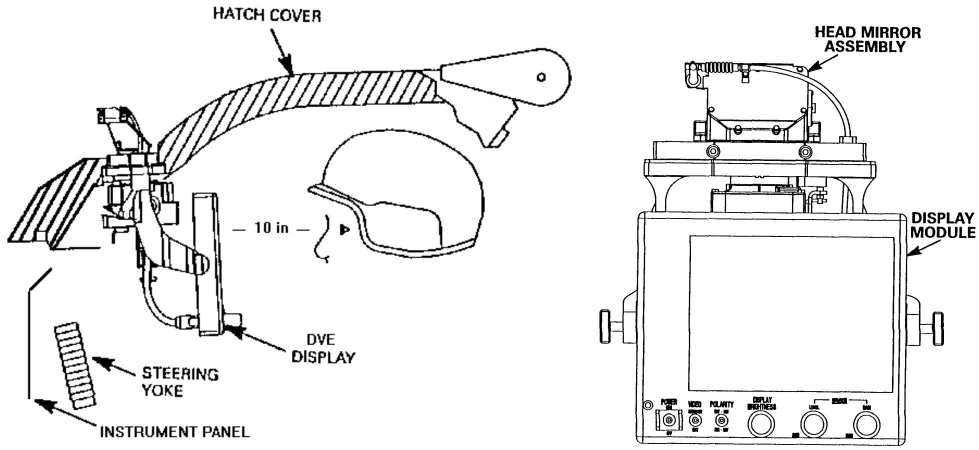

Figure 2. Driver's Vision Enhancer Sensor and Display Modules (combat vehicle variant)

During development and initial testing of the DVE several issues were raised that could best be resolved by measuring the impact of specific variables on driver performance. Some of the issues were directly related to DVE system design, while others were operational in nature, with indirect design implications. Several studies were designed to address these issues. The studies required completion in a timeframe that would allow results to be used in the development process while retaining traceability to user requirements and the operational environment.

One of the potential applications for the DVE is in the fleet of vehicles used by Military Police (MP) in support of their combat mission when driving and performing battlefield surveillance. The MP School requested support in conducting a Concept Experiment Program (CEP) to evaluate the operational utility of the DVE.

- What is the utility of the DVE when performing the driving portion of the MP mission?

One of the acknowledged hazards in the operational environment of tactical vehicles is that of detecting drop-offs (a sudden change in elevation of greater than 3 feet). Using night vision devices has an impact on depth perception and the ability to detect obstacles, including drop-offs. In a previous effort conducted under the Army's Small Business Innovative Research (SBIR) program, an analysis of ground vehicle accidents involving currently fielded night vision devices such as NVG and the AN/VVS-2, showed that the leading hazard encountered in the accidents was a drop-off that was not detected by the driver. The consequence of driving off the precipice was sometimes fatal[1].

- Can the driver of a vehicle detect the presence of a drop-off when using the DVE?

The specification for the DVE contained conservative criteria regarding nonresponsive pixels in the sensor and display, as well as uniformity criteria between pixels in the display. These criteria have a direct bearing on cost and producability of the DVE system.

- If the nonresponsiveness and nonuniformity criteria are relaxed to reduce cost, is there a negative impact on the display quality such that it results in a reduction in driver performance?

2. DRIVER PERFORMANCE MEASUREMENT

To address this series of questions, a data collection program was developed that would use a combination of objective data and driver evaluations to form the foundation from which DVE project decisions could be made. Once the questions were broken down into components that would determine what data was needed, it became obvious that an initial set of data to quantify driver visual behavior was necessary to work in concert with the drop-off detection issue. As a result, several linked projects were identified to address the issues specified above. The projects discussed in this paper are:

- MP Concept Experimentation Program of the DVE
- Drop-off detection
- Driver visual behavior quantification
- Nonuniform/nonresponsive pixel study

To conduct these studies, an instrumentation package was developed that would fit in a variety of military vehicles including the HMMWV and M2/M3 Bradley. The instrumentation package consisted of a three-deck Hi-8mm video tape recorder for recording DVE video, video from a day video camera, video from an Intensified Charge Coupled Device (ICCD) camera (as a surrogate for NVG video), and crew audio. The audio system provided headsets for the vehicle and test crew as an intercom and means to record driver comments. A Global Positioning System (GPS) provided an on-board record of vehicle position. In addition, a GPS base station was used to provide differential GPS enhancement of vehicle location. An eye-tracker system was installed in the package to track driver eye movements and record dwell times. The eye-tracker eye camera, IR illumination source, scene camera, and dichroic mirror were mounted on a DH-132 combat vehicle crewman (CVC) helmet so that it could be used in a variety of tracked and wheeled vehicles. A computer was used for controlling and logging data from the GPS and eye-tracker systems.

2.1 Military Police Concept Experiment Program test of the DVE

The Directorate of Combat Developments (DCD) at the U.S. Army Military Police (MP) School, Fort McClellan, AL, felt that the DVE would provide a significant enhancement to the MP mission. To determine the military utility of the DVE for this mission a Concept Experiment Program (CEP) test was conducted[4]. PM NV/RSTA was requested to provide test planning, data collection, analysis, and reporting support to DCD. DCS Corporation provided the requested support through an existing technical support services contract with PM NV/RSTA. The results of this experiment were to be used to support decisions concerning acquisition of the DVE for use on MP vehicles. This test was conducted at the MP School, Fort McClellan, AL. A total of 10 MP soldiers participated in the test, which was conducted at night over a two-week period. Two night vision devices, the DVE and AN/PVS-7B NVG, were tested concurrently using two HMMWVs on four driving courses. The first iteration during the test used the Military Operations in Urban Terrain (MOUT) site at Fort McClellan. This site had paved roads, buildings and other cultural features found in an urban setting. All driving at this facility was conducted at night in the presence of smoke. Navigation was not an issue during this test. The drivers were told to drive the prescribed course and stop at designated terrain assessment (T/A) points. At each T/A point the driver would announce the obstacles he could see in the vehicle path and what the intended path around the obstacle was. Drivers were graded on their ability to detect obstacles in the road and negotiate the course without striking curbs or obstacles on the course. The second course, labeled Course 1, was a route that used both paved and dirt roads. There were steep inclines, water obstacles, obstructions in the road and deep ditches on both sides of the road. Smoke was used on one leg of this course. Drivers were graded on their ability to negotiate the course and detect the obstacles present at the T/A points. Course 2 was a very rough, rocky road with steep drop-offs to the sides, washouts in the road, and various

obstacles in the road. As on Course 2, the drivers were asked to negotiate the course and detect the obstacles in the vehicle path. Course 3 was conducted over dirt roads that included one water obstacle. Drivers were instructed to negotiate the course as they would during a tactical mission, with safety a paramount concern. There were no T/A points on Course 3. The time to complete this course was recorded to the nearest second. However, due to a concern for safety, drivers were not told that this was a timed trial. During each of the driving trials a data collector in the right seat wearing NVG recorded driver errors and data on the detection of obstacles. The primary function of the data collector was safety.

The conclusions reached during this test were used by the MP School to determine the need for a thermal driving device to support the MP mission. The DVE showed a significant advantage over NVG when obscurants, such as smoke, were present in the environment and when illumination was low. Detecting vehicles and personnel is easier with the DVE due to the thermal signature of these objects. During this test, drivers were able to detect more obstacles when using the DVE. This characteristic is important for accident prevention since the leading cause of accidents when using currently fielded night vision devices is the failure to detect the obstacle. The NVG had an advantage under high illumination conditions and when operating in confined areas. The ability of the driver to scan and see obstacles close to the vehicle when wearing NVG is related to the head-mounted design, compared to the vehicle-mounted design of the DVE.

2.2 Drop-off detection

The central issue addressed during this effort[5] was to determine if the driver could detect a drop-off that is in the vehicle path when using the DVE. For currently fielded systems such as the AN/PVS-7 NVG and the AN/VVS-2 the detection of drop-offs is a major concern. In an analysis of Army accident data over a 10-year period, 34% of the accidents involved drop-offs greater than 3 feet, and an additional 23% involved ditches with a depth of less than 3 feet. By far the leading driver error in these accidents involving NVG and the AN/VVS-2 was that the driver did not detect the drop-off at all, or in sufficient time to stop the vehicle from going over the precipice. Further documentation of these hazards is available in the February 1999 issue of the Army's Safety publication "Countermeasure". PM NV/RSTA needed information regarding driver performance in the area of drop-off detection when using the DVE.

The drop-off detection study is being conducted in three phases. The first phase of the study was conducted as a simple detection test where the drivers were fully cued regarding the presence of the drop-off and were familiar with its location and appearance. This phase provided important information regarding the maximum distances at which we could expect drivers to detect the drop-off under benign conditions. The second phase (discussed in section 2.3) involved a semi-cued detection of the drop-off where the driver was warned that a drop-off was in the vehicle path, but had no familiarity with the drop-off. During this phase the driver wore an eye-tracker while driving the vehicle to provide data on visual fixations during the search task. The final phase is in the preparation stage and will involve a totally uncued search. That is, the driver will not be aware that a drop-off will be in the vehicle path. This phase of the study will yield the most directly applicable data since it most closely replicates the operational environment.

The first phase of the drop-off detection study was conducted in conjunction with the MP CEP discussed in Section 2.1. Nine drivers were used in this study using a HMMWV as the test vehicle. The DVE was mounted in the vehicle and was used as the night vision aid for half the trials, while the AN/PVS-7B NVG were used for the other half. When the NVG were in use the DVE display was stowed in its mounting bracket on the ceiling of the driver's compartment to afford the driver an unobstructed view of the vehicle path. Three drop-off sites were used. The first site was a road cut at the end of a

clearing. When the drivers negotiated a path through the clearing there was a 4 foot drop-off approximately 28 feet wide formed by the road. The driver's visual task was to detect the presence of the drop-off. The second site was that of a dismantled bridge. The western-bound approach road to the bridge terminated in a 9 foot drop-off into a stream approximately 120 feet wide. The driver's visual task was to detect the drop-off at the end of the road. The third site was the opposite side of the bridge. The eastern-bound approach road terminated in a 3 foot high berm followed by the 9 foot drop-off. At this site, the driver was asked to detect the berm and the drop-off. Safety was a primary concern during this test. To assure that the vehicle and occupants did not inadvertently drive off the drop-off a number of safety precautions were taken. One of the precautions was to acquaint each driver with the drop-off site. This meant that the driver's visual task was that of a cued search. That is, the drivers knew that there was a drop-off ahead of the vehicle, and they knew the exact location and configuration of the drop-off. We knew that this would yield "best case" data, but it would be valuable nonetheless.

Each driver performed two trials at each site with each of the two night vision systems. The order of presentation was counterbalanced to prevent order and fatigue effects. Each trial was started with the vehicle at a position where the driver did not have line-of–sight to the drop-off. As the vehicle moved forward at a slow speed (2-3 MPH) the driver was to guide the vehicle down the prescribed path and announce when the drop-off was detected. This spot was marked on the GPS data using a keystroke on the computer keyboard. Once the detection was made, the vehicle reversed course to begin the next trial. After each driver completed the four trials at a site (two trials with each device) the next driver in the rotation began a trial. All trials were completed at a site before moving to the next site.

Detection distance to the drop-off was calculated using GPS data enhanced with the differential GPS data from the base station. The mean, minimum, maximum, and 95th percentile distance for each site was calculated. A t-test was used to determine if the differences between the DVE and NVG detection distance data were significant at the 0.05 level. The results were reported to PM NV/RSTA and are currently under review. The data from this test and the visual behavior study in Section 2.3 can be used by commanders in the field to set speed limits when tactical vehicles are operated at night in areas where there is a potential for encountering a drop-off. When vehicle stopping distance and driver response time are combined to give the total stopping distance, these distances should be compared to the detection distances found in these trials. Speeds should be low enough to assure that the vehicle could be stopped safely once a drop-off is detected.

2.3 Driver visual behavior quantification

The purpose of this study[2] was to examine driver visual behavior when using the DVE when driving in a "structured" environment on roads and trails, as well as when attempting to detect drop-offs in the vehicle path in "unstructured" off-road open terrain. The results of this study were used to determine which portions of the DVE display were most frequently used. This information would then be used to determine where symbology could be placed so that it would not interfere with the driving task, and to determine which areas of the display need the most attention in the area of manufacturing quality control. The final purpose in this study was to determine where drivers look in the visual scene to detect a drop-off and what cues they rely on to detect them.

This study was conducted using four drivers, a HMMWV, the DVE, and the instrumentation package at Fort A.P. Hill, VA. Drivers were instructed to negotiate a prescribed course using only the DVE as a visual aid and while wearing the eye-tracker. During the segments that required the detection of a drop-off, drivers were asked to verbalize the detection process and explain how they detected the

drop-off. DVE video, eye-tracker video, driver audio and vehicle position were recorded on videotape for later analysis. The GPS system was used to determine the distance at which the drop-off was detected.

The overall results of the eye-tracker analysis were that the driver spends the majority of his visual search time in the center two-thirds of the display. Drivers almost never look at or above the horizon and rarely look near the left and right edges of the display. This result was expected since the driver would look at objects in the vehicle path to the front, but below the horizon. However, during driving segments in both the road/trail and open terrain environments when drivers were given only general directions regarding the vehicle path, the drivers tended to look close in to the vehicle and use mainly the lower third of the display. When they were told to expect a drop-off in the vehicle path the visual fixations shifted upward toward the horizon (Figure 3). As soon as the drivers were placed back on a road or trail, the fixations shifted back to the near field. This finding has obvious training implications since drop-offs are a major hazard to drivers of military vehicles in tactical settings. Drivers need to look in the far field to give themselves time to detect a drop-off and stop the vehicle before reaching the precipice. If the driver habitually uses only the near field-of-view, the drop-off may not be detected in time to stop. This may help to explain why the accident reports where night vision devices were in use repeatedly show that the driver encountered a ditch or drop-off and did not see it until after the impact. The area of the display used by the driver may also be a function of speed. At low speeds, drivers have a higher probability of detecting a drop-off in time to stop the vehicle, even if they are looking at the bottom third of the display. During this study, we did not systematically vary speed to assess the impact on visual fixation or dwell.

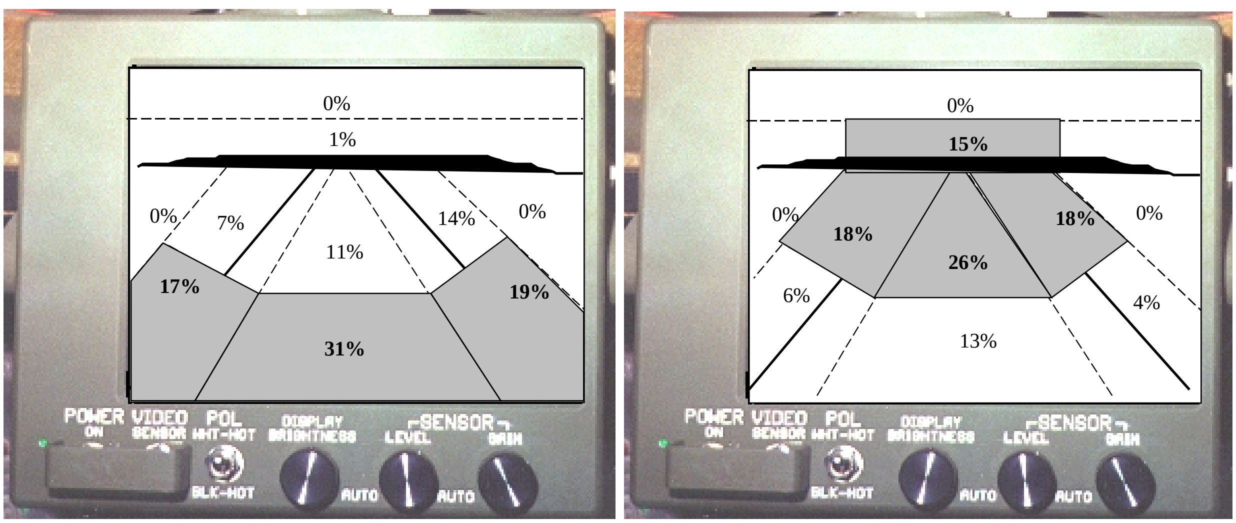

Figure 3. DVE field-of-view divided into areas showing percentage of time used during continuous driving on roads (left) versus driving in the vicinity of a drop-off (right).

The results of drop-off data indicate that the main cues used for detection of a drop-off were occlusion, shading, and motion parallax. These terms are defined below:

- Occlusion – An object that is partially obscured by another will be judged to be further away
- Shading – The variation in scene brightness, texture, or shadows
- Motion Parallax – The relative apparent motion of objects in the field of view as the observer moves

The results of this investigation have important implications regarding hardware quality control. The most important areas to retain tight quality control is in the central and lower two-thirds of the display. The remainder of the display has lesser importance and if the quality is relaxed slightly there should be minimal impact on driver performance. The implications for training are that drivers should be instructed to scan the display and include the far field near the horizon in their scan. This scan is necessary to assure that visual fixations do not overly concentrate in the near field. Driver training should emphasize the detection of drop-offs and show how occlusion, shading, and motion parallax can be important cues to the presence of this hazard. The technical specifications that govern a driver night vision system development should not relinquish the demand for the maximum number of shades of gray in the image, nor should it relax the need for image characteristics that provide the motion parallax and occlusion cues. These findings also relate to the placement of symbology on the DVE screen in that the appropriate location seems to be along the top edge of the screen and along the top half of the left and right edges.

2.4 Nonuniform/nonresponsive pixel study

During the DVE production process there may be some variability in the luminance of display pixels on either a local or global basis. This variation in luminance is referred to as nonuniformity (NU). In a similar vein, there may be some number of pixels either in the sensor or in the display that are inactive, or nonresponsive (NR). To enhance the quality of the DVE system, the specification calls for control over the values of NU and NR during the manufacturing and inspection process. For safety reasons, these characteristics are currently specified conservatively. This has an impact on cost of the system. The challenge posed by PM NV/RSTA was to determine if there might be a degradation in driver performance resulting from a relaxation of these NU and NR specifications. To address this issue a NU/NR experiment[6] was conducted to assess the effect of NU and NR on driver performance. The experimental objective was to provide performance-based data to aid in the evaluation of the DVE specification in an effort to reduce system cost while maintaining driver performance.

The approach to test the effects of NU/NR was to generate DVE video on road courses and progressively degrade the image in a controlled fashion. Drivers were used to view the video under various conditions and their performance was monitored. The process began with DVE video collection at Fort A.P. Hill, VA. Two courses were used that contained a variety of terrain and obstacles. Some of the obstacles were natural, but the experimenter placed some in selected locations. The courses were videotaped using a DVE mounted on a Bradley while traversing the courses at approximately 15 MPH. Each course was driven in both directions providing a total of four scenarios. A 20-minute segment from each scenario was used in the final experiment.

A workstation was used to alter the appearance of the video to test various NU/NR conditions. Four display conditions were generated. The baseline display was a presentation of the video as it was recorded from the DVE, which was a 5% small area, and 15% large area nonuniformity as allowed by the DVE specification. The second condition was that of a NU variation of ± 15% luminance distributed over the entire display. The third condition had a ± 33% luminance variation distributed over the entire

display. The ± 33% global variation is the same as the specification for the AN/VVS-2 Driver's Night Vision Viewer. The final configuration was that of a NR condition containing 250 parts (i.e., subpixels) per million which translates into 65 allowable NR pixels for the 640 x 480 display. This NR condition was based on the worst case commercial specification that could be found.

The drivers used in this test were participants in the MP CEP. The four driving segments were played back using a videotape player and displayed on a monitor in a 640 x 480 window. Each driver was given a briefing on the purpose of the experiment and each was given a printed list of the types of obstacles, hazards and features they needed to detect. Each driver was trained using a 5-minute training scenario showing the kinds of obstacles and features the participants should be watching for. The driver was asked to watch the video and call out the obstacles, hazards, and features as they were detected. An experimenter checked off the objects as they were called out. The drivers used a mouse click to annotate when the object was first detected. The computer used as the display and control device recorded the date, time, velocity, and location data and saved these data to a file for later analysis.

A Latin Square design was used to counterbalance the effects of DVE display conditions, scenarios, and subject group to minimize the effects of practice and fatigue. All drivers were exposed to the four display conditions using different scenarios. The primary performance measure was the response time, or elapsed time between the driver's correct identification response and the time the vehicle passed the obstacle or feature. The secondary performance measure was the percentage of obstacles/features on the predetermined list that the participant correctly identified. Each driver was asked to complete a survey and rate the adequacy of the DVE display condition they just observed for detecting different types of obstacles and features. An ANOVA was performed to test for the significance of the overall differences among the DVE conditions for the response time and subjective ratings.

The main result was that there was no statistically significant difference in percent objects identified or response times between the four DVE display conditions. The response times were slightly lower for the NU conditions than for the baseline or NR conditions. All DVE display conditions tested were rated as adequate or better for detecting obstacles and features.

As a result of these findings, the recommendation was made to PM NV/RSTA that the relaxed levels of NU and NR tested in this study could be considered viable candidates for the specification of DVE quality control in the future. This study indicates that slightly less stringent requirements for NU and NR do not affect driver performance.

3. SUMMARY

This paper has shown that a multidisciplined approach to driver performance measurement can provide benefits to a development program. The series of studies described above has provided a quantitative basis for making decisions on the DVE program. These data can be used to make decisions on cost reduction, training, safety, operations, and overall system performance.

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